Kauri disease cost-benefit analysis

Modelling and analysis of intervention options

NZIER report to Ministry for Primary Industries

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Key points

This report outlines our estimate of quantifiable net benefits of the current funding of the National Pest Management Plan (NPMP) for Kauri Disease (KD).

species whose extinction would be irreversible. Section 1 backgrounds the issue of KD and its current distribution and rate of spread. Section 2 frames the issues using the ecosystem services and total economic value frameworks in contrast to the Deloitte cost-benefit analyses (CBAs) of 2018 and 2019.

Section 3 describes some stylised spread modelling that provides some guidance on the relative benefit of treating areas or linear tracks to minimise KD spread, and that can be scaled up to cover wider areas in northern North Island.

Section 4 describes the results of our modelling, subject to the limitations of quantification. The principal quantifiable benefit is averted loss of carbon stored in kauri trees, which, if they die, would add to New Zealand's emissions for international reporting. There are other benefits in maintaining other ecosystem services such as soil and water conservation in the forest catchments and benefits to Māori in protecting their taonga and all New Zealanders in protecting biodiversity, but these cannot be reliably quantified or valued at this time.

We estimate that additional mitigation measures in the NPMP could more than break even in delivering carbon benefits in excess of costs. However, this depends on there being a high rate of KD spread, a high value attached to retaining carbon stores in kauri forests. It also depends on the speed at which carbon from dying trees is assumed to be emitted into the atmosphere. All these are subject to considerable uncertainty at present. There are wider unquantifiable benefits, including the high significance of kauri to Māori, that cannot be valued in this report but which can be considered as offsetting the net costs of NPMP in protecting an iconic

Table 1 Combining costs and benefits of NPMP measures

	Base analysis	High C Price	Early carbon loss	0.5% KD growth	3% DR
Total analysis	*PV$m*	*PV$m*	*PV$m*	*PV$m*	*PV$m*
PV benefits	1.5	5.7	8.7	9.6	11.6
PV costs	28.0	28.0	28.0	28.0	29.5
NPV	**-26.5**	**-22.3**	**-19.3**	**-18.4**	**-17.9**
BCR	0.05	0.20	0.31	0.34	0.39
Partial analysis: P4 only					
PV benefits	1.5	5.7	8.7	9.6	11.6
PV costs	8.4	8.4	8.4	8.4	8.9
NPV	**-6.9**	**-2.7**	**0.3**	**1.2**	**2.7**
BCR	**0.18**	**0.68**	**1.04**	**1.14**	**1.30**

Source: NZIER

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1 Introduction and scope

1.1 Objective of the report

The Government has allocated $28 million over 4 years (part of $32 million over 5 years) to fund a National Pest Management Plan (NPMP) to treat Kauri Disease (KD). The programme will be led by a Kauri Protection Agency within the Ministry for Primary Industries (MPI).

MPI requires a cost-benefit analysis (CBA) of the proposed NPMP for KD that meets the minimum standards of Part 6 of the National Policy Direction for Pest Management 2015. Having examined a previous CBA and an Addendum CBA prepared by Deloitte in 2018 and 2019 respectively, in our assessment, this cannot be easily amended to meet MPI's requirements to demonstrate costs and benefits have been adequately considered, chiefly because they do not include enough information on the links between intervention costs and infection rates to re-model the detailed effect of changes in intervention level. They also have a very narrow frame of analysis which includes valuing kauri at their value as felled timber, which is problematic for assessing a programme whose purpose is the protection of indigenous forest species from degradation.

A revised CBA would focus on the rate of spread of KD and its effect on forest deterioration under different scenarios of intervention (including zero intervention).

1.2 Background

New Zealand's kauri forests in Northland, Auckland, and Coromandel are being infected by *Phytophthora agathidicida* (PA). PA is a fungus-like organism that causes the disease of kauri trees, a taonga and keystone species on which ecosystems depend.

Symptoms of KD were reported in 1972 on Great Barrier Island, but it was not identified on the mainland until 2006. By that date, DNA-based phylogeny enabled a reassessment of the pathogen, and it was recognised as a new species, which was formally designated as PA in 2015.[1] Surveillance has revealed the infected trees are widely spread across the Northland region, in Auckland with a concentration in the Waitakere range, and in Waikato, in parts of the Coromandel Peninsula. There are no known infected trees in the Bay of Plenty region.

PA has been present over a long period, and although it is unclear how fast it is spreading and killing trees, neither effect appears to be rapid. Tree roots may be infected before symptoms become apparent (an interval known as the latency period), and the time between above-ground symptoms appearing and tree death is highly variable but commonly takes 1-10 years, with smaller trees declining most rapidly. Some trees have become infected and quickly deteriorated in proximity to other trees that remain healthy, so there appears to be variation in resistance of trees to PA, the causes of which are not known and could be resulting from tree genetics or micro-environmental variation.

There is currently no known cure for PA. However, kauri are slow-growing trees and there is a risk of PA spreading so far that there are insufficient uninfected areas where young trees

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[1] R. E. Bradshaw et al (2020) *Phytophthora agathidicida*: research progress, cultural perspectives and knowledge gaps in the control and management of kauri dieback in New Zealand; https://bsppjournals.onlinelibrary.wiley.com/doi/full/10.1111/ppa.13104

can grow to reach maturity and replace older trees. This threatens succession in forests and extinction of kauri and the sustainability of the ecosystems and species that depend on it.

As shown in Table 1, forests with kauri at risk of infection are predominantly in Northland, with smaller concentrations in the Coromandel and Auckland. Bay of Plenty is KD free.

Table 2 Distribution of kauri forest in regions with recorded PA infections

Estimates as at September 2018

Districts	Hectares of kauri forest	Share of total kauri forest area	Share of total district or region land area
Far North District	249,919	39.3%	34.1%
Rest of Northland Region	85,188	13.4%	13.2%
Rodney	2,211	0.3%	(part of Auckland)
Auckland	128,615	20.2%	26.7%
Coromandel (Waikato Region)	169,955	26.7%	74.1%
Rest of Waikato	24,907	3.6%	1.1%
Bay of Plenty	31,900	4.6%	2.6%
Total	**692,695**	**100.0%**	**15.9%**

Source: NZIER, drawing on data from MPI

Table 2 shows estimates of the areas of public and private land affected. This shows 2,200 hectares confirmed to have infection out of 114,261 hectares surveyed. Infection appears to be higher on public land (at nearly 3%), which may be because of greater access by people to DOC-managed land or may partly reflect a higher likelihood of PA being detected on public lands. At just under 2% of the total forested areas infected, the impact does not yet seem large, but these proportions are likely to be understatements due to limited monitoring of all forest areas.

Table 3 Areas of kauri forest infected by PA

Estimates as at September 2018

Districts	Surveyed Forest Total Hectares	PA infected hectares	Share of infected hectares	Infected share of surveyed area
Public land	49,827.5	1,369.7	62.2%	2.7%
Private ha	64,434.4	830.8	37.8%	1.3%
Combined land	**114,261.9**	**2,200.5**	100.0%	**1.9%**

Source: NZIER, drawing on data from MPI

How large an understatement depends partly on the rate of spread of the disease. In two previous cost-benefit analyses by Deloitte (2018, 2019), spread rate was assumed to start with an annual increase in the area infected expressed as a percentage of the area infected at the beginning of the year and then assumed a constant change in the annual increase in the area infected. For example, the scenarios in the 2018 CBA assumed the area of forest infected would increase by 1.35% in the first year but that the rate of infection would change by a constant number of percentage points each year, -0.05 to +0.05 depending on the scenario. But apart from uncertainty around assumptions as to the rate of spread, this is unlikely to be realistic in light of diffusion and spread models used in biosecurity incursion modelling. A linear growth assumption is also not informative about the effects of different interventions, which may have varying levels of impact on other activities and effectiveness in curtailing the spread.

The spread of PA is likely to occur in three ways:

- Natural spread, manifested by the expansion of the frontier of the infected area as the infection spreads from tree to tree
- Animal vector assisted spread, as infected soil is transferred from place to place in the hooves of animals that grub in the earth (principally wild pigs): this is likely to spread from infected areas according to the foraging range of the vector species
- Human vector assisted spread, as infected soil is transferred from place to place in the footwear or gear of people visiting kauri forest areas: this is likely to spread either
  - Linearly along tracks used by humans, with movement along the track corridor initially but some spread around the track from either people straying from the track or with infected material deposited off track by erosion or other processes
  - Sporadic infection by humans, using uncleaned gear with infected material transported via vehicle to spots of entirely new areas of forest infection.

Human, and to a lesser extent animal, vectors increase the rate of spread across the forest over the natural spread without vector assistance. Human vectors using walking tracks will spread infection along the full lengths of the track in a relatively short time. They will also spread infection into the heart of a forest if that is where the tracks go, compared to natural spread that will tend to hit the edge of a kauri stand or forest and work its way into the centre. Both natural spread and walking spread will grow to a period of peak spread as the infection boundary expands from the respective source to some point before total infection; after which the spreading boundary is increasingly likely to hit other areas that are already infected, so the rate of new infected area comes down. Sporadic infection is potentially far-reaching, bringing infection to new sites with perhaps tracks running through them, where infection can spread unconstrained by existing infected areas nearby.

Scientific knowledge of the rates of spread and where PA is found is incomplete and may be biased as current observations, and diagnoses of PA have concentrated on more accessible forests and on trees close to the tracks. Further research is required, and Auckland Council is currently conducting a new survey that will enable it to compare impacts of mitigation measures compared to the situation that prevailed before mitigation.

Other basic matters that we assume for this analysis include:

- There are no known cures for KD, and currently, eradication is practically not possible
- Treatment options for diseased trees are few, principally use of phosphite (which seems to allow kauri to recover from the disease but does not remove the PA infection)
- Sites known to have had KD for the past 30 years still have kauri and regeneration, so the increase in severity appears to be slow

- But it is not known why KD is as widely distributed as it is
- It is unknown how KD is affected by other environmental stressors or overall forest health, but it is assumed that a healthy, less disturbed forest will be more resilient
- Compliance with behaviour changing mitigation measures varies with the messaging around why measures are needed and public acceptance of the need for action.

2 Framing for economic analysis

CBA is an approach to comparing what would happen in future with and without a particular course of action being followed. It is commonly used to assess policies or projects with costs and benefits enumerated in dollar terms to provide a common unit of comparison.

The result of the analysis is an assessment of whether the proposed course of action is expected to result in benefits in excess of its costs. Sensitivity analysis can be applied to test the robustness of results to changes in assumptions and inputs used in the analysis, which is useful in the case of great uncertainty or deficient information on the consequences of the policy or project, and the problem being addressed.

We understand that Māori object to the monetary valuation of kauri and do not regard the protection of kauri in cost and benefit terms, but rather consider the protection of taonga as provided for in the Treaty of Waitangi, to be pursued regardless of economic cost. We acknowledge that not everything can be satisfactorily valued in monetary terms, and when that happens, they need to be considered alongside, but outside, the monetary CBA.

2.1 Total economic value and ecosystems services

The basis of valuation in CBA is people’s or society’s willingness to pay to obtain a benefit or their willingness to accept compensation for giving it up. This is most easily done when the economic consequences of an action can be quantified and applied market values, but this is not to say that the only values that count in CBA are those observable in a market or that all items are valued as if on a commercial basis. The value to society includes costs avoided by protecting the quality of the environment and savings in costs that would have been spent in the absence of a particular action.

Two other frameworks supplement this broadening of CBA beyond market prices. One is the Total Economic Value (TEV) approach, which says that the economic value of protecting environmental assets is a combination of its value for current use activities, the value of retaining it for future uses, and the non-use value that society holds in preserving things for their own sake, with no particular use in mind

The second supplementary framework is the Ecosystem Services (ES) approach of drawing connections between physical environment changes and natural functions to things of value for human activity. The ES divides ecosystem services into four categories:

- Cultural services, such as providing outlets for recreation, cultural and aesthetic appreciation, biodiversity and natural heritage, sources for scientific and educational endeavours[2]
- Provisioning services, such as the production of food, fibre, energy, clean water
- Regulatory services, such as forests’ contribution to reducing erosion and sedimentation of water sources, absorbing and transpiring water to reduce the

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[2] Cultural in this context refers to all activities contributing to community culture, not tied to any specific ethnic group. This follows the categorization established by the Millennium Ecosystem Assessment (2005). https://www.millenniumassessment.org/en/index.html

incidence of flooding, storing carbon for climate change amelioration, providing shade to reduce animal stress, and cleaning air, by filtering out some suspended matter

- Supporting services such as photosynthesis, nutrient recycling, soil formation and insect pollination, on which all other biological services depend.

With few exceptions (such as hydroelectric generation), provisioning services are largely derived from extractive activities, such as harvesting fish stocks, felling trees, or gathering other food and materials from an ecosystem. These are mostly traded through markets, so their values are relatively easy to determine. Some of the cultural and regulatory, and supporting services may be available through market trades, but most of them are not fully covered by market prices and require a non-market valuation technique to monetise them.

As an illustration of the relative values of these different ecosystem services, an estimate is provided in Landcare's 2012 report on Ecosystem Services in New Zealand.[3] A chapter on land-based ecosystems estimates the value of forest ecosystems, including mature indigenous forest (podocarp, broadleaved and beech) and exotic commercial forests, together covering 6.3 million hectares or 23% of New Zealand's land area.[4] Raw material production is the most important provisioning service (mainly but not exclusively from commercial exotic forestry) and accounted for 49% of forests' gross ecosystem service value. The second most important value source was erosion control (15% of gross value), the third was climate regulating carbon storage (11% of gross value), and the fourth was waste treatment (10%). On these estimates, half the economic value of forests to New Zealand is attributable to non-market values of ecosystems services, or 35% of the net value after adjusting to remove potential double-counting in the estimate.[5]

In those estimates, some provisioning services and all of the supporting, regulating and cultural ecosystem services were not subject to market transactions and, in principle, needed to be valued using non-market valuation studies. In the absence of suitable New Zealand studies, the estimates used a range of overseas non-market valuation studies. The values, therefore, do not represent New Zealander's willingness to pay and should be regarded as illustrative only. They do indicate that there can be substantial value to society at large from forest ecosystem services that are not visible in market exchanges.

The purpose of valuation in a CBA is to provide a commensurable way of comparing costs and benefits to arrive at an estimate of likely net benefit. The values used do not imply commercialisation or privatisation of aspects of the natural environment but rather an intention to ensure environmental effects are not implicitly valued at zero in the analysis. Nevertheless, not everything can be satisfactorily valued in monetary terms, and when that happens, they need to be considered alongside, but outside, the monetary CBA.

2.2 Relevance for Kauri Disease

In the case of PA infection, a problem exists in the spread of infection and the severity of KD and its consequences for people's beneficial uses and enjoyment of the forests. In a cost-benefit framework, the size of this problem can be enumerated by estimating the stream of

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[3] Dymond JR ed. (2012) Ecosystem services in New Zealand – conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand https://www.landcareresearch.co.nz/publications/ecosystem-services-in-new-zealand/

[4] Murray Patterson and Antony Cole (2012): "Total Economic Value" of New Zealand's land-based ecosystems and their services; in Dymond JR ed. Ecosystem services in New Zealand – conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand

[5] Patterson & Cole (2012) argue that soil formation, nutrient cycling and erosion control are not final demand services and hence their value is indirectly subsumed in other estimates – hence their removal from total economic value.

benefits and costs supplied by the forests over time in the absence of PA infection, and comparing this with the benefits and costs supplied in the presence of PA. The first estimates the forest value at risk, the second the value of damage inflicted by PA. In estimating damage, critical factors are the rate of spread of PA, which can be measured in terms of the incremental change in trees or hectares affected per year and the severity of infection's impacts on the benefits provided by the trees.

In the same framework, options for managing PA can be compared against the outcome of unmanaged PA spread. Options may differ in their effectiveness in slowing the spread rate or reducing the severity of PA on the benefits provided by the trees. In either case, the avoidance of the cost of unmanaged PA is a benefit that can be compared against the cost incurred for each option.

In 2018 Deloitte prepared a Cost Benefit Analysis of the NPMP for KD, comparing a light and a full version of the NPMP against three other options: the status quo, kauri extinction and forest closure. The monetary calculation was limited to programme costs for government and regional councils under each option, and the quantified benefits were confined to the value of kauri as sawn timber and the value of carbon stored in their trunks. The results suggested forest closure offered the highest net benefits, but the analysis did not account for the value caused by loss of forest access for recreation, food gathering and other matters. The results also suggested the light NPMP would have larger net benefits than the full NPMP, implying that increasing spending from the light to the full NPMP would not be cost-effective.

In 2019 Deloitte revised their analysis and offered two new estimates in which they increased the costs of the light NPMP while leaving its benefits unchanged and lowered the costs of the full NPMP while leaving its benefits unchanged. The results then showed the full NPMP had the largest net benefits. However, Deloitte valued kauri for both its timber (which implies harvesting) and carbon storage (which implies not harvesting) which are inconsistent. Although there is an argument that if a tree dies, there is value in salvaging its timber before it decays, harvesting is incongruous with the purpose of the NPMP of protecting kauri forest. Accounting for salvage assigns a positive value to what the NPMP is intended to prevent. This analysis does not account for timber salvage.

The Deloitte CBAs also discussed qualitatively the value of kauri as an attraction for tourism, comparing tourism expenditure in regions with kauri with those regions' value added. Statistics New Zealand's Tourism Satellite Accounts suggest that in the 2018 year cited by Deloitte, tourism contributed about 4% to those regions' value added directly, and a further 3% indirectly after accounting for flow on spending by businesses supplying the businesses directly servicing tourists. They also identify 58% of tourism spending coming from domestic tourists who, if unable to visit kauri sites in those regions, are likely to spend their money elsewhere in those regions or the rest of New Zealand. The critical question with tourism is how much would the absence of kauri reduce foreign tourists' time in New Zealand or reduce their spending while here? Tourism, like recreation, uses "cultural" services in terms of the ecosystem services framework, but the tourism value at risk is likely to be much smaller than suggested by the numbers cited by Deloitte.

2.3 Steps in a cost-benefit analysis

The NPMP aims to improve responses to KD over the previously prevailing system of separate responses by agencies and regional councils, by providing a co-ordinated national programme. It has been granted $28 million over four years – distributed as $8 million per year for three years and $4 million in the fourth year, with potentially a further $4 million for the fifth year. This grant is substantially less than the NPMPs covered in the Deloitte CBAs. It is likely to be spent on:

- Capability building among iwi and local communities (ca. 50%)
- Monitoring and surveillance activities to identify the health of the forest (ca 10%)
- Research into forest resilience and treatments of affected trees (ca 10%)
- Short term measures of restricting disease spread (ca 30%), including:
    - Installing hygiene stations for boot and gear cleaning at track ends
    - Upgrading a proportion of tracks to reduce vulnerability to PA spread
    - Track closures to exclude people from at-risk areas
    - Fencing to prevent farm livestock from straying into and through kauri forests
    - Restriction of soil and plant material movements in kauri forests.

A CBA proceeds through a series of steps:

- Establish the likely situation to prevail in the absence of NPMP intervention, to act as the counterfactual against which to compare the impact of the intervention
- Define a series of intervention options to reduce the impacts of PA spread
- Identify, quantify and value impacts to the extent possible to build up a picture of the flow of future impacts and the difference between the intervention options and the counterfactual
- Generate results and test their sensitivity to changes in input assumptions.

The last bullet above lends itself to examining a series of scenarios for how results might change with different configurations of intervention. For instance, with a large area of potentially affected forest and limited funding, there will be choices whether to spread intervention thinly over as wide an area as possible or concentrate it on particularly hotspots for infection spread.

2.3.1 Establishing the counterfactual

This is the situation that is expected to prevail in the absence of intervention. PA is present widely across Northland and Auckland and into the Coromandel in the Waikato, but mostly in small pockets rather than continuous tracts. It has a background level of spread from infected areas (mostly on the flat or downslope, rather than uphill) which has been variously estimated at 1 metre, 3 metres or even 5 metres per year.

If the infected area was a single circular tract and its boundary was spreading at 1, 3 or 5 metres per year (as suggested by some literature), the current infected area of 2,200 hectares would expand in 10 years by 17, 50 or 84 hectares respectively, equivalent to annual average growth rates of 0.1%, 0.2% and 0.4%. That background rate of spread would increase the more the infected area is broken up into the smaller forest areas, and spread also increases the more access tracks penetrate the forests for people and animals to potentially spread infection.

In the case of KD, what will happen without intervention? In the short term, PA will spread, and KD will manifest more widely, although on past experience, not at a rapid rate. If kauri trees die, then it is likely that some other large podocarps, like totara, rimu or miro that are not affected by PA, will fill their space, and there may be adjustments in other parts of the ecosystems and species distributions as species dependent on kauri are displaced by those which are not. As long as affected areas remain forested, many of the ecosystem services will remain similar to those of kauri forests. Principal exceptions are in the volume of carbon stored in kauri trees and species that replace them, and the extent to which cultural ecosystem services with respect to biodiversity protection and customary Māori interests in kauri and associated species as taonga would be compromised.

Table 3 summarises the effect of unchecked KD. This assumes that for many of the regulatory and supporting ecosystem services, the effects of kauri forest and other forests are more or less the same. More noticeable differences between the counterfactual and intervention to protect kauri forest would occur if decaying kauri loses more carbon than can be absorbed by other trees growing in its place; and if the cultural and biodiversity value of contraction of kauri forest area exceeds that of the forest types that replace it.

Table 4 Effects of Kauri Disease

Ecosystem service	Kauri forest	Other podocarp forest
Cultural and biodiversity value	Loss of kauri and associated species	Increase in other podocarps and associated species
Carbon storage value	Loss of carbon stored in kauri	Growth in carbon stored in other podocarps
Air quality	Filtering effects of forest area	Filtering effect of forest area
Watershed management	Soil retention, water flow regulation, reduced sediment and flood risk	Soil retention, water flow regulation, reduced sediment and flood risk
Supporting services	Pollination, nutrient cycling, soil formation	Pollination, nutrient cycling, soil formation

Source: NZIER

As new podocarp forest would take time to fill the ecological niche left by kauri, there will likely be some transitional loss of ecosystem service value in the interim period before the new podocarp forest reaches maturity. Similarly, with carbon storage, there may be a lag between the peak emission of carbon from dying kauri and the maximum sequestration in replacement trees.

This implies that the biggest impacts in the counterfactual are:

- “Cultural” ecosystem service impacts caused by depletion of an iconic keystone species and dependent ecosystems, which is:
  - A loss to Māori mana whenua of a taonga through damage to a taonga species
  - A loss for all New Zealanders from the depletion of an iconic species
  - A weakening of endemic biodiversity, contrary to New Zealand’s national and international commitments to the protection of biodiversity

    - Loss of specific cultural and recreational opportunities around kauri forest
- Loss of carbon storage for ameliorating climate changing emissions, as tree death releases large volumes of stored carbon that will only slowly be reabsorbed by new trees growing to take the place of lost trees.

The counterfactual should take account of other factors that might change in future in the absence of intervention. That includes the potential impact of climate change in shifting the geographical range in which kauri are likely to survive and result in some current areas of kauri forest being no longer viable. That is a long term issue that is beyond the timeframe of interest for this analysis.

2.3.2 Potential mitigation options

Against this background, responses to KD are likely to include:

- Measures to reduce the spread of KD to buy time for more effective cures to arrive
- Measures to improve research into the spread of KD and the impact of forest health in resisting its spread and severity
- Measures to improve the capability of detecting and responding to KD, particularly among iwi and local communities who are in best position to monitor conditions on the ground.

There are various potential responses to controlling PA spread.

- Pathogen management: e.g. treating individual infected trees repeatedly with phosphite to bring temporary relief, which may extend the life of infected trees, but is not a cure.
    - The long term effect of phosphite use on soils and ecosystems is unknown
- Visitor management, including:
    - Creating an obligation on visitors to clean gear like boots and poles that touch soil, between visits to separate forest areas
    - Installing boot cleaning stations at track ends supplied with trigene cleanser, the effectiveness of which depends on visitors’ compliance rate
    - Upgrading track infrastructure with boardwalks or compacted stone surfaces and drainage, the effectiveness of which depends on visitors’ compliance and design in keeping people on the track and preventing boot residue run-off onto soil
    - Other measures such as issuing controlled area notices or attaching conditions to the permitting system for specific activities in the forest
- Border control measures that include:
    - Track closures to exclude people such as the rāhui applied over the Waitakeres
    - Restrictions on the movement of plant and soil material into or around kauri forests
    - Livestock exclusion and adherence to farm management plans to manage PA risks
    - Creation of sanctuaries around uninfected stands, excluding human and animal vectors.

The NPMP is oriented to managing pests. However, it serves a higher objective: protecting the kauri as a taonga species and all the ecosystems and other species that depend on kauri; in short, protecting biodiversity.

2.3.3 Quantifying and valuing impacts to the extent feasible

In economic terms, how to intervene in kauri protection depends on which measures achieve the most benefit in averting kauri loss for the least cost in resources used. The value of intervention is a function of:

- Uptake of measures by people affected, or compliance with restrictions imposed
- Effectiveness of measures in curtailing PA spread (e.g. tracks curtailing run-off into soils)
- Cost of the measure.

In the context of KD amelioration, long term measures like establishing sanctuary forests with fences to exclude people and animals from spreading PA should be highly effective, with fences creating a high degree of compliance, but costs could also be high due to both the installation and maintenance of fencing and to the exclusion of people from areas they are accustomed to accessing. Installing boot cleaning stations at track ends is relatively inexpensive, but its effectiveness is critically dependent on people observing boot cleaning protocols when accessing the forest.

In principle, all the items summarised in Table 3 above are capable of being assigned dollar values, which would enable a value for loss of kauri in the counterfactual to be compared with the cost of measures to protect kauri and reduce that loss. An economic value based on public willingness to pay for additional protection of kauri could be estimated using various non-market valuation techniques. The purpose of such values is not to enable privatisation of kauri, but rather to indicate public preferences for allocating funding to kauri protection that reduces the risk of KD spread, compared to all the other demands on finite incomes. Monetisation in CBA is not a precursor to commercialisation. It is simply a way of gauging the importance of different actions on a commensurable basis.

It is clear from the total economic value and ecosystems services frameworks that the value of kauri is not confined to the timber or carbon contained in its trunk. Accordingly, the approach used in the Deloitte CBAs is limiting and potentially misleading.

However, existing non-market valuation studies in New Zealand use variable methods, tend to be site-specific and are not informative to protecting kauri forest from PA spread.

In this analysis, we do not attempt to value all potential measures in the NPMP, most of which were still subject to final review by the incoming advisory and governance arrangements at the time of writing. Rather, we focus on the primary objective of preventing the spread of PA and use a model of spread to identify the likely effectiveness of selected potential short term measures for reducing that spread. Given this and cost estimates on the different measures, we consider cost-effectiveness of different measures ($ per hectare of infection spread avoided). Other measures like capability building among local communities and iwi target the long-term uptake and effectiveness of useful measures. These are less suited to quantification at this time and are discussed more qualitatively.

3 An approach to modelling dispersion

3.1 Infection rates

Our analysis is based on a natural spread rate of 4 metre per year at the frontier of the infected area and an infection rate of 20 metre per year along walking tracks. The 20 metre spread may look high, but it is along the 1 metre wide track only; the spread rate from the edges of the track into the forest is the natural rate of spread. The 20 metre figure should not be viewed as the upper bound of a range of average spread. It is a consequence of tracks enabling faster penetration into the forest, opening up new frontiers for lateral spread as it does. Based on corroboration from experts, a spread rate along tracks that is five times as fast as background frontier spread would be a reasonable starting assumption.

Empirical data on the rates of natural infection is sparse and variable:

- MPI observed that the *Natural spread rates within infected stands are not known, but are likely to be 1 to 5 metres per annum.*[6]
- *A report to Auckland Council*[7] *referred to previous calculation of soil-borne spread rate and movement, which is 3m per annum* (This estimate is taken from (Beever et al., 2009*)* which is quoted in more detail in the following bullet point.)
- *Affected trees covered an area of c.10ha, representing a 5~10-fold increase since 1972. This corresponds to a rate of spread of c.3m per year on the assumption of circular areas of infection, a rate comparable to that of P. cinnamomi spread in southwestern Australia* (Strelein and others 2006) [8][9]

3.2 Disease spread model

The disease spread model is based on a grid of 500 x 500 squares that each represent 1m^2 – the grid represents an area of 25 hectares. The disease is assumed to spread as follows:

- Natural spread – 4 squares per year for all uninfected squares that touch an infected square.
- Walking spread – 20 squares per year from any infected square in both directions along one of two tracks that bisect the opposite sides of the grid and intersect in the middle of the grid.

Figure 1, Figure 2 and Figure 3 below show how the area of infection differs for forests affected only by natural spread and forests where the natural spread is accelerated by walking. The infection enters the forest grid at the four starting points of the walking tracks.

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[6] E-mail from Travis Ashcroft (MPI) to the Deloitte team on 31 October 2018.

[7] Hill, Lee, Waipara, Nick, Stanley, Rebecca and Hammon, Christina. 2017. 'Kauri Dieback Report 2017: An investigation into the distribution of kauri dieback, and implications for its future management, within the Waitakere Ranges Regional Park Version 2: Update June 2017'.

[8] Beever, R.E., Waipara, N.W., Ramsfield, T.D., Dick, M.A., Horner, I.J., 2009. Kauri (Agathis australis) under threat from Phytophthora? Proceedings of the 4th International Union of Forest Research Organizations (IUFRO) Working Party 7.02.09. Phytophthora in forests and natural ecosystems. Monterey, California, 26-31 August 2007. General Technical Report PSW-GTR-221. USDA, Forest Service, Albany, California, USA. Pp. 74-85. See page 78.

[9] Beever et al., 2009 cites the following reference for the comment on Australian spread rates - Strelein, G.; Sage, L.W.; Blankendaal, P.A. 2006. Rates of disease expansion of Phytophthora cinnamomi in the jarrah forest bioregion of southwestern Australia. In: Brasier, C., Jung, T., Oswald, W., eds. Progress in Research of Phytophthora diseases of forest trees. 3rd International IUFRO Working Party Meeting, 11-18 Sept 2004, Freising, Germany. Forest Research, Farnham: 49-52.

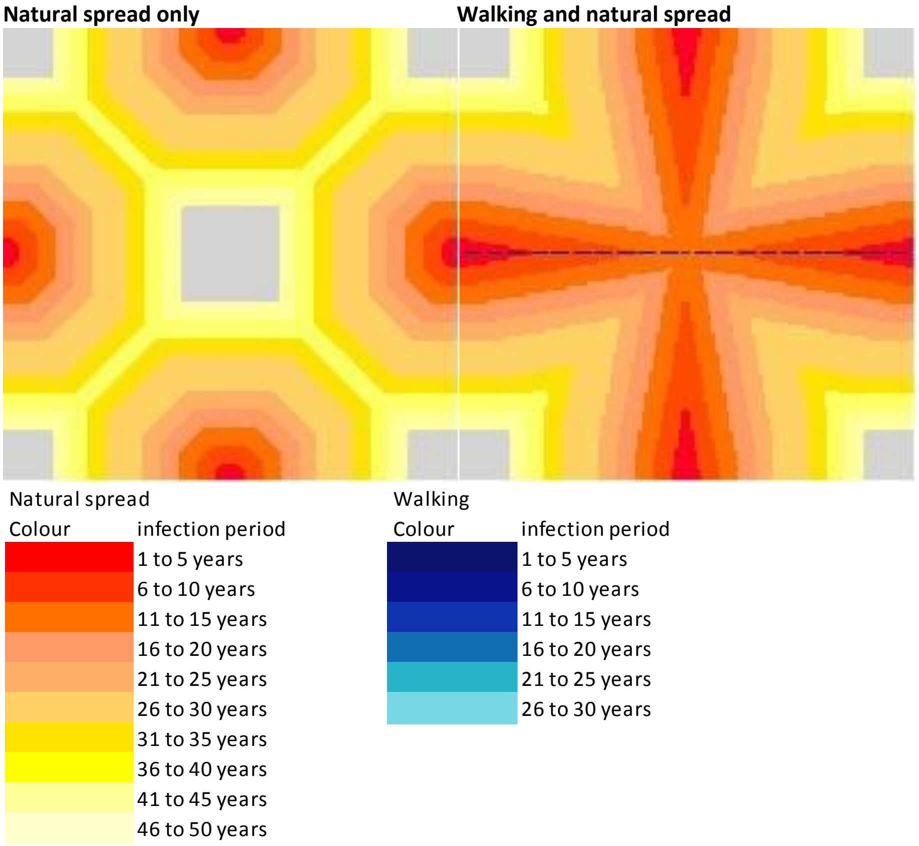
The infection period bands refer to the year of infection – one is the first year of infection, 50 is the last year of infection.

Comparison of the area and rates of infection under the two scenarios gives an estimate of the benefit (delay in the rate of infection from closing or upgrading walking tracks). This estimate is sensitive to the size of the grid modelled and the spread rate from walking as opposed to natural spread.

For this example:

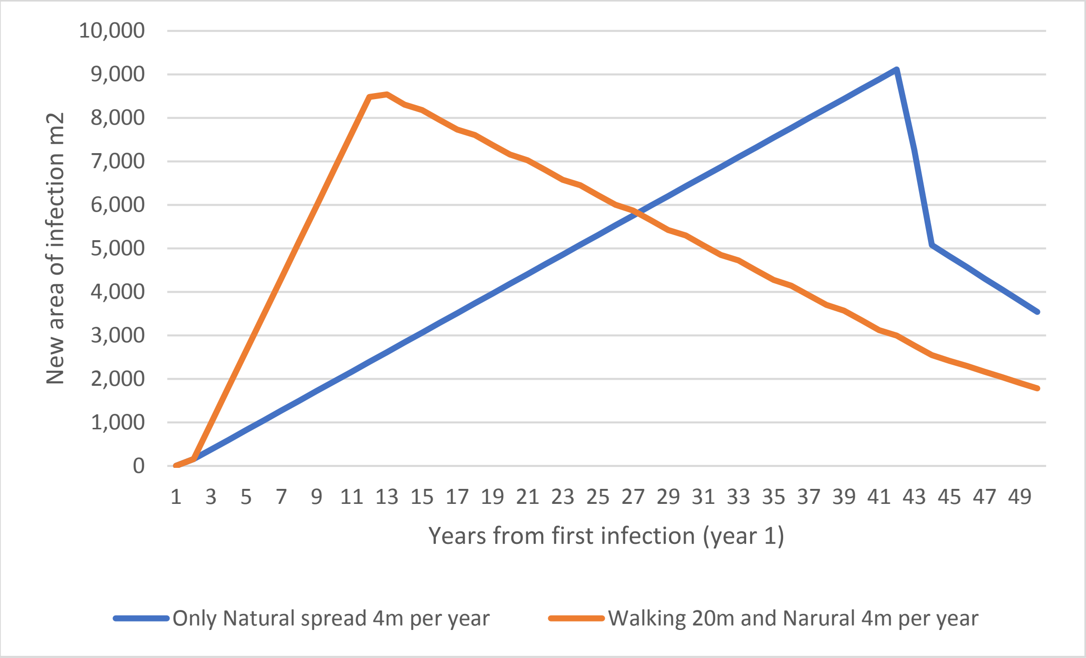
- The area of new infection for a forest affected by walking peaks in year 13 at about 8,600 m^2 while the area of new infection for a forest affected only by natural spread peaks in year 42 at about 9,100 m^2.
- Although the tracks are 500 metres long, walking spreads the infection the full length of both tracks after 11 years. (The vertical infection path is not visible in the right-hand side of Figure 1 but it is the same as the horizontal path).
- Slowing the spread of infection due to walking along the tracks to the natural rate (by closing or hardening the tracks) delays the spread of the infection by about 8 to 12 years.
- Natural spread affects the centre of the forest last, whereas walking carries the infection into the centre of the forest during the first 11 years of the infection.

Figure 1 Diseased area – natural vs walking accelerated disease spread



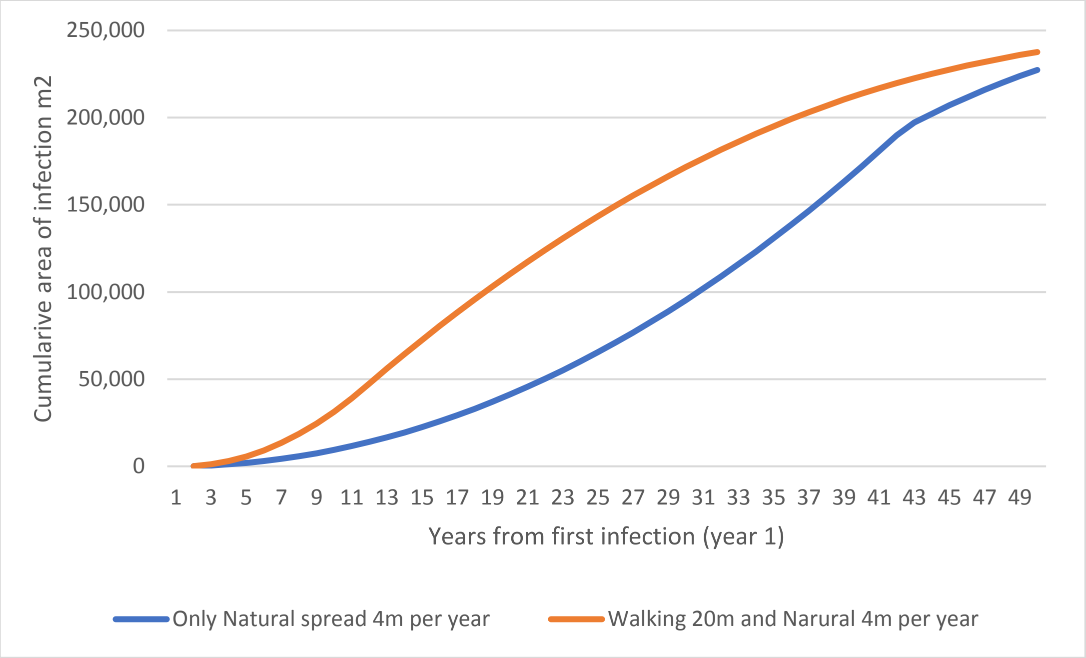
Source: NZIER

Figure 2 New infection area – natural vs walking accelerated disease spread



Source: NZIER

Figure 3 Area infected – natural vs walking accelerated disease spread



Source: NZIER

3.3 Model sensitivities

Our modelling of the infection spread is based on the movement of the pathogen through the soil or along a walking track from four point sources. Accordingly, the speed of the spread of the infection is slower the larger the size of the forest, and the delay in infection achieved by closing or improving tracks is longer the larger the area of the forest. As an indication:

- A 49 ha forest will have infection rates with:
    - natural spread only of 1.9% after 10 years, 15.4% after 25 years and 55.3% after 50 years
    - natural spread accelerated by walking of 6.4% after 10 years, 39.0% after 25 years and 79.8% after 50 years
- A 100 ha forest will have infection rates with:
    - natural spread only of 0.4% after 10 years, 3.1% after 25 years and 12.7% after 50 years
    - natural spread accelerated by walking of 1.6% after 10 years, 11.8% after 25 years and 39.2% after 50 years

The average size of most kauri stands as calculated in Table 13 is less than 49 ha.

4 Combining costs and benefits

We understand NPMP funding is divided into four categories, with proportional allocations roughly as follows:

- Ongoing mitigation (30% of funding)
- Monitoring and surveillance (ca 10% of funding)
- Science and research for management (ca 10% of funding)
- Empowering Mana Whenua (ca 50% of funding).

Table 4 outlines some of the management measures enabled by the new NPMP. Ongoing mitigation covers a range of potential measures aiming to reduce the risk of the spread of PA from existing infested areas. As the location of all infested trees is not known precisely, these measures may apply to areas known to be infected and other areas not known to be infected. In the case of areas known to be infected, the aim of mitigation is to contain the infection in those existing known areas and prevent its export to other areas. In the case of areas not known to be infected, the aim of mitigation is to prevent the import of infection from elsewhere.

The principal impacts of mitigation vary with the measure: control of soil and plant movements falls primarily on nurseries and plant dealers who supply restoration groups working in the forest. Fencing to prevent livestock straying falls primarily on owners or managers of land adjoining the forests. The other mitigation measures of closing off access, track hardening and installing hygiene stations primarily impact recreational users of the forest.

We assume the NPMP funding is sufficient to maintain existing mitigation funding and enable investment in some new mitigation. To the extent that it is feasible to identify the effect of new measures on reducing the spread of KD and its effect on kauri death, these measures are capable of quantification in a CBA.

Monitoring and surveillance are necessary for ongoing management, identifying where new infections are occurring and how response measures are being complied with. The marginal effect of differences in monitoring and surveillance level are difficult to discern in the short term, so it is not practical to quantify this in the CBA.

Research and science can improve available treatments to contain or resist PA infection, identify significant kauri at risk of infection, and take more targeted measures to protect them. However, it is not possible to assign a probability to research developing a more effective treatment of KD, so this is not quantified in the CBA.

Beyond the mitigation measures, other activities for funding by NPMP have a wider scope of lifting the effectiveness of the mitigation measures in the long term. Capability building among local communities and iwi has the potential to enable earlier detection of PA infection and swifter management responses, regardless of whether this applies to currently infected or not-known to be infected areas. This long term effect, combined with enabling greater involvement of Māori in applying mana whenua, which may be considered enshrined in the Treaty of Waitangi, are difficult to value in the short term, so it is not practical to quantify this in the CBA.

Table 5 Potential management measures under the NPMP

Action	Areas known to be infected	Areas not known to be infected	Principal impacts
Control of soil and plant material movements	Containment of PA at background spread rate	Reducing risk of PA infection to very low level	Nurseries and plant dealers; restoration groups
Exclusion of livestock from forest	Containment of PA at background spread rate	Reduced risk of PA infection to very low level	Landowners adjoining forests
Closure of tracks and areas (rāhui)	Containment of PA at background spread rate	No entry of PA infection into forest	All recreational users denied access to forests
Track hardening	Low risk of PA spread exceeding background rate	Low risk of PA spreading into to new forest, if people stay on tracks	Impacts all people using forest tracks, but misses off-track users
Hygiene stations	Reduced risk of PA spread above background rate	Reduced risk of PA spreading to new forests if people comply	All people accessing forest via stationed entry points
Monitoring and surveillance	Identifying firmer measures of depth and breadth of infected areas, if and when PA arrives in new areas		Groups engaged in monitoring of PA
Research into forest health and treatments	Potential to slow the natural spread of PA by adding new tools to forests' protective armoury		Laboratories used for testing samples and devising new treatments
Capability building	Increased effectiveness in identifying infection and responding to it, reducing risk of further spread		Iwi members involved in kaitiakitanga, volunteers and local communities

Source: NZIER

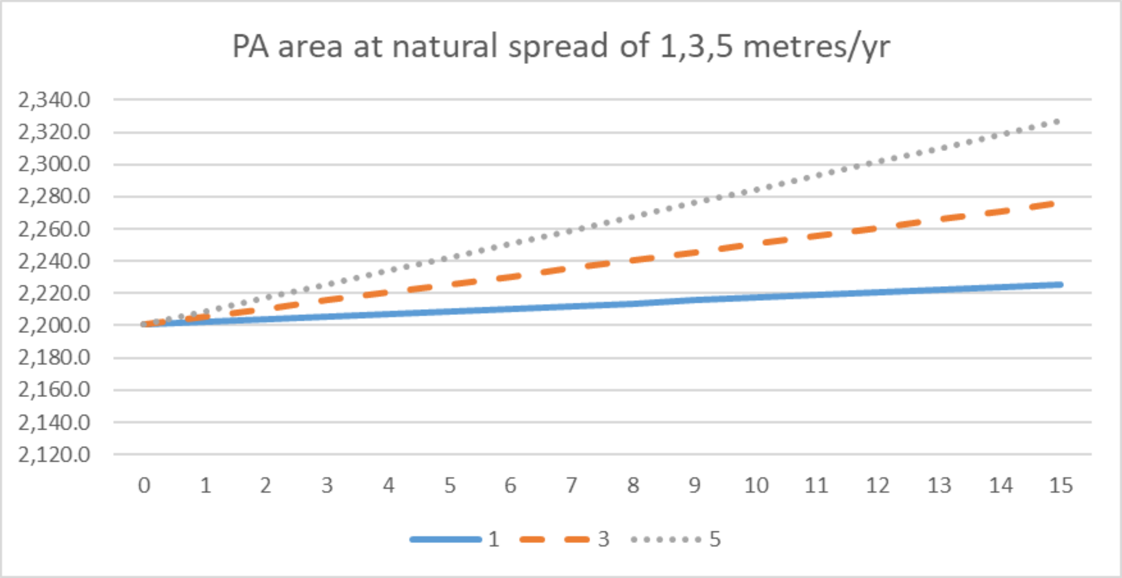
4.1 The counterfactual

Figure 5 shows the area of spread of KD from its current level, applying the rates of 1, 3 and 5 metres per year consistent with existing literature on spread. We assume that literature is consistent with natural spread combined with current management and mitigation responses, which are variable across locations. We also assume that that spread can be represented with the expansion of a single circular block of infection expanding outwards in all directions. As indicated by our distribution modelling, where forests are small (less than 49 hectares) and bisected by tracks, spread within them can be faster. Also, there is the possibility of sporadic spread of infection from people turning up at new uninfected areas with gear that has not been disinfected.

Accordingly, our initial assumptions represent a conservative assumption of spread. The area of KD increases at an average annual rate of 0.1, 0.2 and 0.4,% respectively for the 1, 3 and 5 metre assumptions. We project this over 15 years to coincide with a 10 year horizon after the fifth year of NPMP funding. Compared to a starting area of known KD infection of around 2,200 hectares, at these rates, 15 years would increase that area by between 1.1% and 5.7%. And while this may not seem a large area of infection compared against around 684,599 hectares of forest containing kauri trees, each additional hectare of forest infected contains kauri that could die prematurely due to the disease, to the detriment of the ecosystem services and benefits they provide to people.

Taking account of faster spread along tracks and sporadic outbreaks, area growth rates could be higher than this.

Figure 4 Spread of areas with KD



Source: NZIER

Assuming each infected hectare contains 525 tCO_2-e valued at $73/tonne, these rates of KD spread would compromise stored carbon worth in the range of $0.96 million and $4.85 million. Identifying how new mitigation measures reduce the risk of KD spread and reduce that carbon loss can be valued and included in the CBA.

4.2 Quantifiable benefits from NPMP interventions

4.2.1 Value of stored carbon

Kauri trees are reported to die between 1 and 10 years from becoming noticeably infected with PA. As they decompose, they will release stored carbon into the atmosphere, increasing greenhouse gas emissions. While some carbon will remain locked up in decomposing wood for some years, the Emissions Trading Scheme, and the UN Framework Convention on Climate Change, consider emissions from felled timber to be released as soon as a tree is felled. While kauri trees are not felled by PA and may die standing, there is likely to be a rapid loss of stored carbon after the tree has died.

The Regulatory Impact Statement on the NPMP suggests using 525 tCO_2-e as the average volume of carbon per hectare of kauri forest. This figure is conservative and compares with a value of 543 tCO_2-e per hectare used by the Climate Change Commission in its modelling to represent the carbon content of mixed indigenous forest. This is a relatively low number, suggesting either immature kauri, a low density of trees per hectare or both. For mature high forest, the Commission used a figure of 920 tCO_2-e/ha.

Indigenous trees are slow growers, so a kauri dying will emit a large volume of greenhouse gas which will only slowly be offset by a new non-kauri tree growing in its place. Figure 5 shows the carbon sequestered in different indigenous trees at different ages, based on a selection of sequestration estimates of planted trees of known ages and various locations.[10] A mature kauri may have several tonnes of CO_2-e in its above ground biomass; a totara seedling growing in its place would only have acquired 0.02 tCO_2-e in its first 10 years. Even if several totara saplings contest the space vacated by a dead kauri, their combined carbon sequestration would be well short of the carbon emitted by the kauri death. This suggests there could be significant deficit of stored carbon which counts as a net emission for many years after a kauri dies.

Deforestation of old growth forests such as kauri forest releases CO_2 that has taken centuries to accumulate — stored carbon that, once lost, will not be recovered in new planting in current people's lifetimes. So, keeping existing forests standing and maintaining their substantial carbon storage has a significant role in carbon accounting and meeting the Zero Carbon Act target of net zero carbon emissions by 2050.

Figure 5 Carbon sequestration in native tree species over time

Source: Drawing on figures from Tane's Tree Trust

Although there are data on the distribution of kauri forests and some differentiation by kauri density (see appendices) there is insufficient data on the age and size of individual trees to provide an accurate estimate of stored carbon at risk due to KD. Our estimates are therefore indicative, using the 525 tCO2-e /hectare figure as a base and comparing other figures in sensitivity analysis.

There is a range of values that could be applied to stored carbon:

- $39/t CO2-e, which is approximately the traded price in the New Zealand ETS – this is the clearing price in a market that has been distorted by exemptions, so it is probably an understatement of the societal cost of carbon emissions
- $73.63/t CO2-e, which is the updated value ($65.58) used by NZTA as the social cost of carbon in its transport cost-benefit appraisals – drawn from an Australian study

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[10] Drawing on figures for planted kauri and other native trees from Tane's Tree Trust. https://www.tanestrees.org.nz/site/assets/files/1069/10_5_carbon_sequestration.pdf

- $160/t CO2-e which is the price that the Climate Change Commission considers emissions will need to rise to by 2035 to achieve zero net carbon in 2050.

We model the emission effects of containing KD using the middle and high prices in this range.

4.2.2 Value of recreational impacts

Most of the short term measures for containing the spread of PA have implications for access to forests for recreation. Recreation in specific forests has economic value that manifests in different ways. People choosing to visit a forest for recreation spend money and time in travelling to the forest, so analysis of travel costs of site visitors can give a value of current use of the forest, on the assumption their visit is worth at least as much to them as the costs they incur in making the visit.[11] Analysing the variation in house prices controlling for their internal characteristics and external environment has shown there is a premium for properties closer to forests and open spaces accessible for recreation. Market research type surveys that ask people their stated preference for different types of landscape also shows there is a positive willingness to pay for more natural surroundings, including forests, in the areas being examined –including the full total economic value including values for current use, options for future use, and value of preservation irrespective of any expectation of using a particular landscape.

An overview study in New Zealand suggests the value of a day's recreation is around $75 in a range from $37 to $143, after updating to 2021 values.[12] However, recreation value is location-specific. Bespoke studies for each location produce the most reliable values, but they are expensive and rarely done in New Zealand, and transferring values from other places (e.g. foreign studies) can be misleading. We opt not to value recreation impacts in this CBA, but make the following observations.

Recreation impacts are most likely to occur because of restrictions on access imposed to reduce the spread of KD. While depriving people of recreational opportunities does have an economic cost, if it means people have to travel further for their recreation or miss out on it altogether, the value varies with the availability of substitute recreation opportunities: the more the alternatives, the lower the cost of access restriction. So as long as access restrictions are targeted to kauri forests at risk and alternative recreation sites remain accessible, the economic cost of restriction is likely to be low. The exception is if closure occurs to a forest with a very high value such that there are no close substitutes, in which case closure could impose significant economic cost.

4.3 Other unquantified items

We do not value the item "Other cultural services", which includes all cultural ecosystem services under the Millennium Ecosystem Assessment categorisation, other than recreation. This includes the importance of kauri preservation for mana whenua and impacts on biodiversity of deteriorating health of kauri-based ecosystems. Monetising of these values is problematic, so we just note that impacts would be positive of any measure that reduced the rate of infection and kauri biomass loss compared to the counterfactual.

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[11] There is also economic value associated with the purchase of goods associated with recreational visits – boots, packs, raincoats, fishing tackle etc. These are long-lived items that can be used in a wide variety of locations, and costs are not practically attributable to individual forests and hence excluded from site valuations.

[12] See Richard Yao https://www.researchgate.net/publication/234119293_Non-market_valuation_in_New_Zealand_1974_to_2005

Of the other potential benefits of short term NPMP measures, we assume there will be little difference from the counterfactual in the watershed regulation and supporting services categories, which tend to be fairly similar for all forest covers in similar settings. Forest closures may significantly impact recreation, and this could result in a negative entry in the recreation benefit line in

Table 6. But as long as such closures are selective, cover limited areas and retain readily accessible alternative sites for forest recreation, there would not be a large economic value in such recreational restrictions.

4.4 Assumptions around intervention measures

The quantified CBA focuses on short term intervention measures and their impact on the spread of KD. Those affecting people's access to kauri forests have varying effectiveness depending on the compliance rate of the public in adhering to the measures and also vary with fundamental suitability in particular settings. For instance, although track hardening may discourage people from venturing onto soil or kauri roots, it will have little effect on recreational hunters who commonly venture off tracks.

An Auckland Council survey in which 97% of users said they used the stations as required, and other evidence from DOC that observed use of hygiene stations is rather lower. Auckland Council studies have found that the use of hygiene stations improves when there are track ambassadors at the road ends reminding people of what's required, and it also improves over time as people become familiar with the stations. Hence, we assume that hygiene stations are used by 90% of people entering tracks. We also note that they can potentially reduce the risk from people entering the forest at those points but subsequently going off track (such as hunters). We assume that hygiene stations cost around $21,000 to install new on average and require $500 a year maintenance to keep them functioning.

Hardened tracks are effective in keeping people on the track and avoiding the track spreading that occurs when mud patches form and people seek a route around them rather than through them. They are easy to comply with as long as people stay on the track but do not address risks of people moving off track. They have relatively high costs for installation, so their use would probably be limited.

For our modelling, we assume a track or area closure using a rāhui is most effective at removing people from at-risk areas, but it will be less than 100% effective as some people may ignore it or not be aware of it. The risk of infection of areas under exclusion is a combination of the probability of people entering the area when they shouldn't and the probability of these people carrying infection with them. As both these probabilities are small, their combined probability will be very small, so exclusion should be effective over targeted areas that can be monitored fairly well. Over larger areas with many potential entry points, the probability of non-compliance becomes larger.

4.5 Findings from cost-benefit analysis

In our CBA, we model the effect of an assumed mix of these measures and their assumed effectiveness in reducing the rate of spread of KD and the consequent effect on avoidance of carbon storage loss. We model the NPMP funding over 15 years, i.e. 10 years after the last year of intended funding in year 5. This allows for new investment in mitigation installations such as hygiene stations and track sections, and we also provide for some NPMP funding to be set aside to cover maintenance over the remaining 10 years of the analysis. We apply a 5% real discount rate in the first instance and examine other rates.

We calculate a net present value and benefit-cost ratio across the whole analysis and then across a partial analysis comparing the carbon storage benefits against the costs of short term measures on mitigation. This is because only the short term mitigation measures have an immediate quantifiable connection between the measures put in place and the reduced risk of spreading PA and KD. Other measures are either long term or difficult to quantify. We discuss the implications for the interpretation of results at the end of this report.

Table 6 summarises the results of various runs of our CBA model. The left-hand column shows the base analysis with a range of conservative assumptions on the analysis, i.e.

- A counterfactual spread rate of KD of 0.3%
- A carbon volume of 525tCO2-e per hectare
- An assumption of carbon loss starting 5 years after kauri death (mid-point of the 0-10 year range from the literature)
- A carbon value of $73.63 per tCO2-e
- A discount rate of 5%.

The result of the base analysis is significantly negative, both over the total programme (to be expected) and over the partial analysis of mitigation measures and changes in carbon storage loss. Subsequent columns show the effect of changing key assumptions.

With the high carbon price of $160/tCO2-e, the negative NPV on the partial analysis is reduced by almost a half, and its benefit-cost ratio rises from 0.18 to 0.68.

Further changing the assumption of carbon loss starting in the first year of KD in a new area rather than the fifth year sees the negative NPV on the partial analysis turn positive with NPV of $0.3 million and a benefit-cost ratio of 1.04.

A similar result arises in the partial analysis when combining the $160/t carbon price with lifting the PA spread rate in the counterfactual from 0.3% to 0.5% (but retaining the first carbon loss in year 5, not year 1). Then the partial analysis has an NPV of $1.2 million and a benefit-cost ratio of 1.14.

In the right-hand column, this raised spread rate result is recalculated with 3% rather than a 5% discount rate to achieve an NPV of $2.7 million and a benefit-cost ratio of 1.3; i.e. benefits of averted carbon loss well exceed the costs of mitigation measures under that set of assumptions.

These results for the partial analysis show it is finely balanced. To more than break even, it needs a higher value for averted loss of stored carbon than current ETS traded prices and the higher value in the initial conservative assumptions. It also requires either earlier accounting of carbon emission after tree death or an expectation of a higher PA spread rate in the counterfactual without additional mitigation. A 3% discount rate is not unreasonable at the current low rate of interest offered in the economy. Both the PA spread rate and the volume of carbon at risk in infested forests are uncertain, so if either were higher than is assumed for these current calculations, the present value benefits of the NPMP mitigation measures would be higher than those estimated here, making that part of the analysis look stronger than it does under current assumptions.

Table 6 Combining costs and benefits of NPMP measures

	Base analysis	High C Price	Early carbon loss	0.5% KD growth	3% DR
Monetary benefits	*$m*	*$m*	*$m*	*$m*	*$m*
Other cultural services	0.0	0.0	0.0	0.0	0.0
Recreation	0.0	0.0	0.0	0.0	0.0
Embodied carbon	2.4	9.2	12.6	15.5	15.5
Watershed regulation	0.0	0.0	0.0	0.0	0.0
Supporting services	0.0	0.0	0.0	0.0	0.0
Total NPMP benefits	**2.4**	**9.2**	**12.6**	**15.5**	**15.5**
Monetary costs	*$m*	*$m*	*$m*	*$m*	*$m*
Stock exclusion	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*
Hygiene stations	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
Hygiene maintenance	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
Track improvement	*4.0*	*4.0*	*4.0*	*4.0*	*4.0*
Track maintenance	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*
Area closures	*3.3*	*3.3*	*3.3*	*3.3*	*3.3*
P4: Ongoing mitigation	9.8	9.8	9.8	9.8	9.8
P3: Research/Science	3.2	3.2	3.2	3.2	3.2
P2: Surveillance	3.2	3.2	3.2	3.2	3.2
P1: Capability building	15.8	15.8	15.8	15.8	15.8
Total NPMP costs	**32.0**	**32.0**	**32.0**	**32.0**	**32.0**
Discount rate	5.0%	5.0%	5.0%	5.0%	3.0%
Total analysis	*PV$m*	*PV$m*	*PV$m*	*PV$m*	*PV$m*
PV benefits	1.5	5.7	8.7	9.6	11.6
PV costs	28.0	28.0	28.0	28.0	29.5
NPV	**-26.5**	**-22.3**	**-19.3**	**-18.4**	**-17.9**
BCR	0.05	0.20	0.31	0.34	0.39
Partial analysis: P4 only					
PV benefits	1.5	5.7	8.7	9.6	11.6
PV costs	8.4	8.4	8.4	8.4	8.9
NPV	**-6.9**	**-2.7**	**0.3**	**1.2**	**2.7**
BCR	**0.18**	**0.68**	**1.04**	**1.14**	**1.30**

Source: NZIER

Our estimates suggest that the components of the NPMP funding could break even or better given higher assumptions than the conservative set we used in the bases. The analysis covers the first 10 years after the 5 years of available funding under the NPMP. We do not recommend stretching the analysis out to 50 years in line with Treasury's CBAx model, as over that timeframe, many other factors will change to affect the result.

No other benefit than averted carbon loss can be reliably estimated for the NPMP, but there will be other positive outcomes from slowing the spread of KD and kauri death. In short:

- Slowing the spread of KD will produce cultural ecosystem service benefits, which include benefits for Māori in the protection of their taonga, and benefits for all New Zealanders in the protection of biodiversity
- Recreation impacts could be negative with widespread mitigation that restrict recreational access, but with targeted and dispersed areas of track closures that leave others available, there would be little economic cost for recreation
- Retaining the ecological integrity of kauri forests should produce more ecosystem services of soil and water regulation in the catchments affected
  - Kauri death and loss of canopy cover exposes the forest floor to heavy rainfall, increasing erosion and sedimentation of streams which may reduce channel efficiency in ways that increase flood risk and also affect water quality
  - In the long term, regenerated forest with other keystone species than kauri may be expected to offer similar regulating ecosystem services to kauri forest, but there will be a loss of such services in the interim period covered by this analysis, i.e. an unquantified benefit of forest protection that would add to the benefits in this analysis if fully quantified.

For context, assuming there are 684,599 hectares of kauri forest across northern New Zealand, the $32 million total funding amounts to $46.68 per hectare of forest, or $9.34 per hectare per year. In present value terms, the cost of protection (net of carbon losses avoided) ranges from $38.68 per hectare to $26.12 per hectare across the 5 variant results, or $7.74 to $5.22 per hectare per year. As the mitigation options and capability building include investments that should extend beyond the 5-year funded period, the programme's cost per year will be lower over the period that benefits are received.

The NPMP entails $32 million in funding over the full five year period, with $9.8 million for mitigation funding. The balance of $23.2 million is spent on issues that are difficult to attribute precisely to benefits and remain unquantified and include:

- $3.2 million on research and science to find better treatments for KD
- $3.2 million on monitoring and surveillance to better understand the distribution of KD
- $15.8 million to iwi and local communities to better manage KD in their areas.

All the estimates above are subject to considerable uncertainty. One way to consider the worth of the NPMP is to compare the pay-offs between what could happen with and without the NPMP. If KD spreads slowly and is relatively benign, $32 million could be spent over five years with little gain in reducing the threat on the ground, although there would still be the benefit of some enhanced science research and community capability. If KD is spreading more aggressively, that funding helps contain the resultant damages. If nothing is sent on NPMP and KD is aggressive, much more severe harm will be incurred, touching a wide range of interests across the community.

Table 7 Pay-off matrix for NPMP funding programme

	Benign spread and harm	Severe spread and harm
Investment $32M	$32M over 5 years invested and no gain on the PA front if spread and harm proved to be low; but maybe gain in other areas raising iwi involvement in kaitiakitanga	$32M over 5 years invested and tangible reduction in PA spread and harm; plus other benefits in raising iwi involvement in kaitiakitanga
Investment $0M	Nothing ventured, nothing gained but not much lost either if PA spread and harm is very low	No budgetary cost but large off-budget costs from failing to curtail the spread and severity of PA harm

Source: NZIER

4.6 Economic impacts of the NPMP for employment

In an economic cost-benefit analysis, labour employed on an investment is usually counted as a cost, because it is a resource that could be productively employed in other programmes, with an opportunity cost that must be accounted for in considering the net benefits of the programme. However, for government programmes with a strong regional focus, there is also interest in the economic impact of spending and jobs that a programme or project can bring to local economies.

Ideally, to assess these impacts, the project spending would be input into a model of inter-industry transactions in the local economy. This could show how spending in a given sector in a given region stimulates additional spending and jobs in other industries in the region that either supply the project or benefit from additional spending of workers on the projects who have higher household income. As the operational plan for 2021-22 was still being confirmed at the time of writing this report, we apply a simpler calculation to illustrate the rough magnitude of such effects from the NPMP.

To do this, we estimate the likely economic value added component of an average $8 million per year by applying ratios from Statistics New Zealand’s input-out tables for the sector covering public safety and regulatory services. The $8 million spending on average generates $5.4 million in value added, of which employee compensation accounts for 87% in that sector, or $4.7 million. Dividing through by an average wage of $59,400 would imply the whole programme would directly generate about 79 full-time equivalent jobs a year.

More jobs would be indirectly generated by the flow-on impacts, the size of which can be illustrated with a multiplier that commonly fall in the range of 1.5 to 2. This means the spending could generate a further 39 to 79 jobs indirectly, bringing a total of (direct plus indirect) jobs of 118 to 157 jobs. The larger total impacts will arise if the labour force in affected regions has spare capacity; if labour is constrained, smaller flow-on impacts will arise because the project will compete with other activities and potentially raise their costs or lower their output.

5 Conclusions

This report provides an economic analysis of the NPMP for Kauri Disease.

This is a disease identified fairly recently in New Zealand. There is uncertainty around its spread across northern New Zealand, how fast it is spreading, and why some kauri trees appear more susceptible to it than others. It does appear to be spreading and various national and regional agencies have carried out efforts to contain that spread over the past decade. The current NPMP is an attempt to coordinate those efforts with some national direction.

KD threatens a keystone species in New Zealand's biodiversity, which is taonga for Māori and iconic to New Zealanders at large. Economic costs are likely to result from further spread of the disease, most readily quantifiable of which is depletion of the store of carbon in kauri trees that die, which would count as emissions of greenhouse gases. Various mitigation measures can reduce the spread of KD by restraining access to areas and reducing the risk of transmitting the disease on the feet of people and animals.

A partial cost-benefit analysis of these measures with the benefit of slowing KD spread and the release of stored carbon shows that under some circumstances, the mitigation measures would break even and deliver benefits in excess of costs. Net benefits will be higher if the mitigation measures are targeted at areas where the risks of spread are greatest, such as areas with high density of kauri trees or with tracks running through or around kauri stands.

If the area of infected trees is larger than is currently known, or if the disease is spreading faster than currently appears, the expected value of costs from each successive year of unchecked growth will be higher than in the assumptions used in this assessment, so the benefit of intervention through the NPMP would also be higher than estimated here.

A number of other benefits from ecosystem services are likely from successful mitigation, but they cannot be reliably valued in this study. They would strengthen the case for the NPMP for delivering positive net benefits to New Zealand. There are other costs in the NPMP for which benefits are also difficult to quantify and value, including monitoring and surveillance of disease spread, research and scientific analysis of potential treatments, and building capacity among Māori and local communities most closely affected by kauri and their ecosystems.

This cost-benefit analysis has not delivered a simple number showing the net worth of the NPMP, but it has shown that there are activities funded by the plan that can deliver a benefit in checking the spread of the disease. There are also other benefits of protecting kauri, which, although impractical to quantify and assign dollar values, would raise the net benefits in this analysis if they could be valued. The kauri is an iconic species. The costs of the NPMP are relatively small in reducing the risks to its existence, which would have a significant impact on New Zealanders' wellbeing and sense of identity in their environment.

Appendix A Kauri forest data

A.1 Introduction

We have received two separate databases on the area of kauri forests, one list of infected forests and a list of closed tracks. These sources of information provide partial views of the current prevalence of infection, likely rates of spread and potential for loss of kauri trees. A reconciliation of these partial sources of information into an overview of both the location and density of forests would be very helpful in refining our estimates of the cost-effectiveness of track closure or upgrading.

A.2 Current infection

The sources of data on the current infection are:

- A list of infected areas on public and private land in 2018 – see Table 4. The list reports total infected areas of 1,369.7 ha on public land and a further 830.8 ha on private land. The report includes the total forest area and infection rates for public land but does not provide this information for private land. The list covers 40,436 ha of public reserve in Northland, 319 ha of public reserve in Coromandel and 9,072 ha of public reserve in Auckland. These areas are much smaller than the estimated forest area in the regions shown in Table 11.
- A list of closed tracks as shown in Table 9 and Table 10.

  DOC is closing 21 tracks across kauri land to prevent the spread of kauri dieback. 10 tracks will also be partially closed and upgraded to protect kauri roots and eliminate wet and muddy sections of trac.k[13]

  The list includes information on:

  - type of closure, whether the track will be upgraded, availability of alternative tracks and the level of visitor use which are summarised in the table,
  - whether access to a destination on the track is preserved despite the closure.
  - risk of infection, which is described in the tables as
    - 'high' if the disease is present or there are a large number of trees in the area or the area is wet and muddy
    - 'medium' otherwise.

  The list of closed tracks does not include information on the area of kauri forest affected, the density of trees within the forest or the Infected area. In contrast to the list of infected areas on public land in 2018 data (see Table 4), most of these tracks are in the Auckland or Bay of Plenty Regions rather than the Northland region.

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[13] See www.doc.govt.nz/get-involved/have-your-say/all-consultations/2018/proposal-to-close-tracks-to-protect-kauri/

Table 8 Public reserves with confirmed infection

Area in ha in 2018

Name	Infected	Reserve	Share
Northland			
Waipoua Forest (Pt Northland Conservation Park)	642.0	12,291.7	5.22%
Russell Forest (Pt Northland Conservation Park)	111.8	7,120.6	1.57%
Raetea Forest (Pt.Northland Conservation Park)	15.8	6,605.6	0.24%
Omahuta Forest (Pt Northland Conservation Park)	0.9	6,585.9	0.01%
Herekino Forest (Pt.Northland Conservation Park)	5.2	4,358.6	0.12%
Ranfurly Bay Scenic Reserve	75.4	1,763.7	4.27%
Trounson Kauri Park Scenic Reserve	59.2	593.7	9.97%
Kawerua Conservation Area	1.6	412.9	0.40%
Manaia Ridge Scenic Reserve	8.3	285.7	2.92%
Pukekaroro Scenic Reserve	12.8	133.6	9.56%
Pohuenui Scenic Reserve	0.8	70.9	1.12%
Manaia Ridge Addition Scenic Reserve	3.8	56.5	6.68%
Smokey Hill Scenic Reserve	12.5	42.9	29.13%
Akatere Historic Reserve	0.3	42.2	0.77%
Logues Bush Scenic Reserve	31.0	41.4	74.99%
Robert Hastie Memorial Scenic Reserve	1.4	28.9	5.02%
Waipoua Forest Quarry	0.1	1.4	4.02%
Northland subtotal	**983.0**	**40,436.2**	**2.4%**
Coromandel			
Conservation Area - Whangapoua Forest/Hukarahi	1.2	319.2	0.36%
Auckland			
Great Barrier Forest Conservation area	147.8	7,970.0	1.85%
Okiwi Recreation Reserve	0.0	499.8	0.00%
Kaukapakapa Estuary Scient Reserve	170.1	211.1	80.58%
Goldie Bush Scenic Reserve	7.4	196.2	3.78%
Okura Bush Scenic Reserve	25.0	114.1	21.95%
Pakiri Scenic Reserve	29.6	40.6	72.93%
Albany Scenic Reserve	5.5	40.3	13.71%
Auckland subtotal	**385.6**	**9,072.2**	**4.3%**
Total	**1,369.7**	**49,827.5**	

Source: MPI e-mail correspondence 2018[14]

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[14] Attachment 'Kauri stats per region_08112018' to e-mail from Kim Brown (MPI) to Travis Ashcroft (MPI) and the Deloitte team on 2 November 2018.

Table 9 Track closures after 2018 consultation – Auckland

Location and date of track closure

Track name	Closure	Upgrade	Alternative	Visitor Use	Access	Infection risk
Great Barrier Island						
Whangaparapara Pack Link	Full - Jan 2018		Yes	Low		High
Whangaparapara Peak	Full - Jan 2019			Low		High
Old Lady Walk	Partial - Jan 2018	Partial	Yes	Low	Lookout	High
Hauraki		Partial	Yes		Hut	
Booms - Orange Peel Corner	Partial - Nov 2018	Yes		Medium	Summit	Avoids Kauri
Hihi Trig to Kopu Hikuai Road Summit	Part - Nov 2018					High
Devcich Kauri Track	Full - Oct 2018		Yes			High
Hihi Stream to Motutapere Tt	Full - Oct 2018	No - high cost		Low		
Waipaheke Motorbike Track	Full - Nov 2018					High
Lynch Stream Tramping Track	Partial - Oct 2018	Partial			Motor	
Maratoto 4x4 Road & Extreme Loop	Partial - Nov 2018	Partial - High cost		Medium	Hut	High
Moss Creek Camp-Pinnacles Hut/Hydro Camp Jn	Partial - Nov 2018	Yes		High	Experience	
Twin Kauri Short Walk	Partial - Oct 2018	Partial - High cost	Yes		Hut	High
Wainora Tramping Track	Partial - Oct 2018			High	Experience	Medium
Wharekirauponga Walk	Partial - Nov 2018		Yes	Low		High

Source: DoC list[15]

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[15] https://www.doc.govt.nz/get-involved/have-your-say/all-consultations/2018/proposal-to-close-tracks-to-protect-kauri/

Table 10 Track closures after 2018 consultation – Northland and Bay of Plenty

Location and date of track closure

Track name	Closure	Upgrade	Alternative	Visitor Use	Access	Infection risk
Northland						
Kauri Bush Track	Full - Nov 2018	High cost	Yes	Low		Medium
Hukatere Track	Full - Nov 2018	High cost		Low		Medium
Lookout Track	Full - Nov 2018		Yes		Experience	High
Toatoa Track	Full - Nov 2018	High cost		Low		Medium
Tutamoe Track	Full - Nov 2018		Yes	Low		Medium
Bluff Stream Kauri to Waitengaue Hut Track	Full - Nov 2018					Medium
Bratty's Bush Track	Full - Nov 2018	High cost		Low		Medium
Cullen Road – Massey Road	Full - Nov 2018					
Massey Road to SH 1	Full - Nov 2018	Not possible				Medium
Pukemoremore - southern section of Russell	Full - Jan 2019		Yes			High
Te Ranga Trig - northern section of Russell	Full - Jan 2019					High
Bay of Plenty						
Bluff Stream Kauri Track	Full - Nov 2018	Not possible				Medium
Cashmores Clearing Track	Full - Nov 2018		Yes			Medium
Mangakino Stream Track (Dicky Track-County Rd)	Full - Nov 2018		Yes			Medium
Wairoa Stream Track	Full - Nov 2018		Yes			Medium
Te Rereatukahia Hut Track	Partial - Nov 2018	Partial upgrade	Yes		Hut	High
Kauri Route, Te Kauri Park	Full - Oct 2018	High cost		Low		Medium

Source: DoC list[16]

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[16] https://www.doc.govt.nz/get-involved/have-your-say/all-consultations/2018/proposal-to-close-tracks-to-protect-kauri/

A.3 Area of kauri forests and density of kauri trees

The two sources of data[17] on kauri forests both report the density of kauri forests but use different definitions of the forest that are included:

- ‘All ecosystems’ – a broad definition of forests that includes 90,856 ha of forests with a 0% density of kauri trees and a further 438,859 ha of forests with a density of kauri trees of less than 1% and 19,953 ha of forest with kauri tree density at or above 20% – see Table 11.
- ‘Kauri ecosystems’ – a narrow definition of kauri forests where kauri account for 20% to 100% of the canopy, which includes 19,890 ha of forest – see Table 12.

Table 11 All ecosystems – forest area grouped by density of kauri trees

Forest area in ha grouped by density of kauri trees in 5% bands

Density band	Coromandel	Northland	Auckland	Waikato	Bay of Plenty	Total
0% < to =< 5%	123,098.2	289,535.1	130,593.5	66,088.9	31,814.2	**641,129.9**
5% < to =< 10%	1,549.2	7,643.7	6,489.7	1,327.6	2.0	**17,012.1**
10% < to =< 15%	1,106.5	2,385.5	2,118.1	101.1		**5,711.2**
15% < to =< 20%	744.4	1,324.3	9,353.6	1,879.3	83.9	**13,385.5**
20% < to =< 25%	114.0	180.0	780.2	12.7		**1,086.8**
25% < to =< 30%	42.0	19.0	121.7	7.7		**190.4**
30% < to =< 35%	5.4		150.9			**156.3**
35% < to =< 40%	84.8	398.3	1,307.4			**1,790.6**
40% < to =< 45%		358.0	95.3			**453.3**
45% < to =< 50%	114.4	47.0	239.3	1.1	0.3	**402.1**
50% < to =< 55%		6.1	89.2			**95.4**
55% < to =< 60%	354.4	19.4	153.4			**527.2**
60% < to =< 65%			86.3			**86.3**
65% < to =< 70%	37.5	2.7	37.6	11.4		**89.1**
70% < to =< 75%		139.7	94.0	64.6		**298.3**
75% < to =< 80%	975.8	738.8	80.9	4.2		**1,799.7**
80% < to =< 85%		94.5	4.9			**99.4**
85% < to =< 90%	8.7	111.6	123.9			**244.2**
90% < to =< 95%	4.1	21.0	15.5			**40.5**
95% < to =< 100%		1.0				**1.0**
Total	**128,239.5**	**303,025.8**	**151,935.4**	**69,498.5**	**31,900.3**	**684,599.5**

Source: MPI database, ‘Kauri stats per region_08112018.xlsx, Kauri ha per Region -ALL ecosystems

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[17] Attachment ‘Kauri stats per region_08112018.xlsx’ to e-mail from Travis Ashcroft (MPI) to Deloitte team sent after 1 November 2018.

Table 12 Kauri ecosystems – forest area grouped by density of kauri trees

Forest area in ha grouped by density of kauri trees in 5% bands

Density band	Coromandel	Northland	Auckland	Waikato	Bay of Plenty	Total
5% < to =< 10%	2.9					**2.9**
10% < to =< 15%						
15% < to =< 20%						
20% < to =< 25%	744.4	1,046.0	8,838.9	1,879.3	83.9	**12,592.6**
25% < to =< 30%	114.0	180.0	780.2	12.7		**1,086.8**
30% < to =< 35%	42.0	19.0	121.7	7.7		**190.4**
35% < to =< 40%	5.4		150.9			**156.3**
40% < to =< 45%	84.8	398.3	1,307.4			**1,790.6**
45% < to =< 50%		358.0	95.3			**453.3**
50% < to =< 55%	114.4	47.0	239.3	1.1	0.3	**402.1**
55% < to =< 60%		6.1	89.2			**95.4**
60% < to =< 65%	354.4	19.4	153.4			**527.2**
65% < to =< 70%			86.3			**86.3**
70% < to =< 75%	37.5	2.7	37.6	11.4		**89.1**
75% < to =< 80%		139.7	93.7			**233.4**
80% < to =< 85%	975.8	738.8	80.9	4.2		**1,799.6**
85% < to =< 90%		94.5	4.9			**99.4**
90% < to =< 95%	8.7	111.6	123.9			**244.2**
95% < to =< 100%	4.1	21.0	15.5			**40.5**
Total	**2,488.4**	**3,182.2**	**12,219.1**	**1,916.4**	**84.1**	**19,890.1**

Source: MPI database, ‘Kauri stats per region_08112018.xlsx, Kauri ha per Region’

Table 13 All ecosystems – average forest area grouped by density of kauri trees

Area in ha

Density band	Coromandel	Northland	Auckland	Waikato	Bay of Plenty	Average for all regions
0% < to =< 5%	43.6	22.4	21.7	43.0	63.4	**26.9**
5% < to =< 10%	22.5	78.8	55.0	221.3	2.0	**58.5**
10% < to =< 15%	24.6	99.4	25.2	25.3		**36.4**
15% < to =< 20%	27.6	47.3	42.5	60.6	3.2	**40.3**
20% < to =< 25%	3.1	25.7	25.2	6.4		**14.1**
25% < to =< 30%	2.6	1.7	12.2	7.7		**5.0**
30% < to =< 35%	1.8		12.6			**10.4**
35% < to =< 40%	4.7	16.6	26.1			**19.5**
40% < to =< 45%		51.1	23.8			**41.2**
45% < to =< 50%	4.8	5.9	7.3	0.2	0.3	**5.5**
50% < to =< 55%		3.1	29.7			**19.1**
55% < to =< 60%	44.3	2.8	25.6			**25.1**
60% < to =< 65%			7.2			**7.2**
65% < to =< 70%	4.7	2.7	3.4	3.8		**3.9**
70% < to =< 75%		7.8	2.2	4.0		**3.9**
75% < to =< 80%	162.6	19.4	3.9	1.4		**26.5**
80% < to =< 85%		47.3	4.9			**33.1**
85% < to =< 90%	2.2	3.3	7.3			**4.4**
90% < to =< 95%	4.1	3.5	1.9			**2.7**
95% < to =< 100%		0.1				**0.1**

Source: Kauri stats per region_08112018

Table 14 All ecosystems – share of forest area weighted by density of kauri trees

Area in ha

Density band	**Coromandel**	**Northland**	**Auckland**	**Waikato**	**Bay of Plenty**	**Total**
5% < to =< 10%	5.9%	16.9%	7.1%	0.3%	0.1%	**30.4%**
10% < to =< 15%	1.2%	5.8%	5.0%	1.0%	0.0%	**13.0%**
15% < to =< 20%	1.3%	2.7%	2.4%	0.1%		**6.6%**
20% < to =< 25%		2.0%	14.3%	2.9%	0.1%	**19.3%**
25% < to =< 30%	0.2%	0.3%	1.5%	0.0%		**2.1%**
30% < to =< 35%	0.1%	0.0%	0.3%	0.0%		**0.4%**
35% < to =< 40%	0.0%		0.4%			**0.4%**
40% < to =< 45%	0.3%	1.2%	4.0%			**5.5%**
45% < to =< 50%		1.2%	0.3%			**1.6%**
50% < to =< 55%	0.4%	0.2%	0.9%	0.0%	0.0%	**1.5%**
55% < to =< 60%		0.0%	0.4%			**0.4%**
60% < to =< 65%	1.6%	0.1%	0.7%			**2.4%**
65% < to =< 70%			0.4%			**0.4%**
70% < to =< 75%	0.2%	0.0%	0.2%	0.1%		**0.5%**
75% < to =< 80%		0.8%	0.5%	0.4%		**1.7%**
80% < to =< 85%	6.0%	4.5%	0.5%	0.0%		**11.1%**
85% < to =< 90%		0.6%	0.0%			**0.6%**
90% < to =< 95%	0.1%	0.8%	0.9%			**1.7%**
95% < to =< 100%	0.0%	0.2%	0.1%			**0.3%**
Total	**17.3%**	**37.6%**	**40.0%**	**4.9%**	**0.3%**	

Source: MPI database, ‘Kauri stats per region_08112018.xlsx, Kauri ha per Region’